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Division of Engineering Laboratories
Hydraulic Laboratory Branch

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

MODEL STUDIES OF THE RIVER OUTLET WORKS
TIBER DAM--MISSOURI RIVER BASIN PROJECT
MONTANA

Hydraulic Laboratory Report No. Hyd-402

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
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Commissioner's Office--Denver
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Hydraulic Structures and Equipment Section
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Laboratory Report No. Hyd-402
Compiled by: D. Colgate
Checked by: W. E. Wagner
Reviewed by: J. W. Ball
Submitted by: H. M. Martin

Subject: Model studies of the river outlet works--Tiber Dam--Missouri River Basin Project, Montana

PURPOSE OF THE STUDY

This model study was made for the purpose of developing a stilling basin which would adequately dissipate the energy of the high velocity flow issuing from the Tiber Dam river outlet works high pressure slide gate and pivot valve, and to determine the best placement of the gate and valve.

CONCLUSIONS

1. The recommended stilling basin as shown in Figure 10 will operate satisfactorily for all flows up to the maximum discharge, 1,400 cfs. For the maximum discharge the tail water elevation could vary between 2825.6 and 2831.5. This basin should contain (a) nine chute blocks on the downstream portion of the parabolic chute floor, (b) six baffle piers 12.13 feet downstream from the chute blocks, and (c) a dentated sill near the downstream end of the basin.

2. The pivot valve jet will cause some turbulence and splash in the basin (Figure 9D). This rough water is not considered harmful or otherwise objectionable.

3. The indicated scour in the loose sand model channel floor immediately downstream from the basin was about 3 feet deep after about 10 hours of operation at maximum discharge, 1,400 cfs, and minimum tail water, elevation 2825.6 (Figure 12) and about 2 feet deep for the same time and discharge at maximum tail water, elevation 2831.5 (Figure 13).

INTRODUCTION

Tiber Dam is located on the Marias River in north central Montana and is a part of the Missouri River Basin Project (Figure 1). The dam is an earth-fill structure about 4,350 feet long and 200 feet high with the crest at elevation 3021.0. The flood control spillway, with a maximum capacity of 51,700 cfs, is located at the right abutment of the dam.

In an early plan, a canal outlet works was located at the left abutment at elevation 2955.29 (Figure 2). A 6-foot-diameter pipe for future power development was located to the left of the spillway and had an intake sill at elevation 2870.0. This pipe was used for river diversion during construction of the dam. A 22-inch outlet conduit paralleled the pipe between the gate chamber and valve house and was controlled by an 18-inch butterfly valve (Figure 2).

As construction of the dam neared completion, it was found necessary to use the 6-foot-diameter pipe as a river outlet conduit and abandon plans for the canal outlet works. This proposal necessitated the installation of a 5- by 5-foot high pressure slide gate at the downstream end of the 6-foot conduit, and the design of an outlet works stilling basin to dissipate the energy of the flow from the high pressure gate and from the 18-inch pivot valve. (The 18-inch butterfly valve of the original design had been replaced with an 18-inch pivot valve.)

<u>High pressure slide gate</u>. The 5- by 5-foot high pressure slide gate with the downstream invert of its frame at Station 37+54.71 and elevation 2823.06 was tilted downward 15°. The piping to the slide gate consisted of a 72-inch-diameter conduit, a 72-inch-diameter, 15° vertical bend of 30-foot radius, and a 72-inch-diameter to 60-inch-square transition.

<u>The stilling basin</u>. Beginning at the gate, the chute floor sloped downward 12°22' for 55 feet, the basin floor continued horizontal for 51 feet, then upward on a 6:1 slope for an additional 26 feet, making an overall basin length of 132 feet. The width of the basin increased from 5 feet 6-1/2 inches at the gate to 24 feet at the downstream end of the 12°22' slope, then continued at this width to the end of the basin.

<u>Energy dissipating devices</u>. The basin included 12 chute blocks on the downstream end of the 12°22' slope, 6 baffle piers on the basin floor 12 feet downstream from the chute blocks, and a dentated sill 33 feet downstream from the baffle piers.

The pivot valve. The 18-inch pivot valve was located at Station 37+47.02 and elevation 2827.19, 9 feet 3 inches to the right of the high pressure gate. The valve was directed downward 15° and the axis converged 9° with the gate center line. The floor of the pivot valve chute was 3 feet wide and in the same plane as the sloping gate chute floor.

Model studies were made to assure the proper proportions and operation of the stilling basin and to determine the best placement of the high pressure gate and pivot valve. Construction in the field was progressing concurrently with the model study. Very close day to day coordination and cooperation between the designers in the Dams Branch and personnel in the Hydraulic Laboratory assured that the contractor at the dam site would be informed of the design features as they were developed.

THE INVESTIGATION

The Model

The 1:15 scale model (Figure 3) included the high pressure slide gate and pivot valve, a portion of the approach piping for each, the stilling basin, and a tail box 10 feet wide and 16 feet long which contained an erodible sand channel, a tail water control gate, and a sand trap (Figure 4A). Instrumentation consisted of a point gage for tail water elevation measurement, an 8-inch orifice-venturi meter for discharge determination, and a manometer and piezometer tap for reading the pressure head upstream from the pivot valve. Water was furnished from the laboratory reservoir by a portable pump and returned to the reservoir after passing through the model.

Operation of the Preliminary Stilling Basin

The flow at the exit of the stilling basin was quite smooth and evenly distributed for tail water elevations between 2828.5 and 2821.5 with the gate opened 100 percent and with the maximum design discharge of 1,400 cfs. Because of diversion releases at the prototype the excavated channel downstream from the basin could not be cross sectioned, and therefore the expected tail water elevation could not be accurately determined prior to the initial stages of the model study. A computation based on the slope and cross section of the river channel downstream from the exit of the 1,800-foot-long outlet channel indicated the tail water elevation for maximum discharge might be as low as 2822.0, and it was thought unlikely that it would be higher than 2828.0. Thus the preliminary design basin would contain the hydraulic jump within the range of estimated tail water elevations.

For tail water elevation near jump sweep out, elevation 2821.5, the general flow in the basin was acceptable, but as the tail water elevation increased the roller upstream from the crest of the jump became increasingly turbulent. At tail water elevation 2828.5 the surging flow of the roller rushed against, and was forced away from, the gate frame with such violence that the structure might be endangered. When the tail water was below elevation 2825.0 the flow from the gate spread the full width of the floor of the gate chute and impinged against the end of the right retaining wall of the pivot valve chute producing an undesirable high fin of water as shown in Figure 5A.

Corrective Design Changes, Stilling Basin

Chute floor and walls. The cause of the unsatisfactory flow condition where the pivot valve chute entered the gate chute was eliminated by making the right retaining wall of the gate chute continuous past the pivot valve chute exit up to the height of the water surface of the jet from the gate (Figure 5B).

The preliminary tests indicated that the length of sloping chute downstream from the gate should be shortened to improve the operation of the basin at high tail water. The length of this chute could be decreased by directing the jet from the gate into the basin at a steeper angle than the slope of the preliminary design; however, the gate could not be tilted at an angle steeper than 15° (as initially installed) because of the physical restrictions imposed by the pipe bend upstream and the location and elevation of the gate house. Therefore, consideration was given to changing the profile of the gate chute floor.

The new gate chute floor was parabolic in profile and followed the path of a free jet tangent to the downstream end of the gate frame invert and with a velocity of 56 fps at this point. (Fifty-six fps is the velocity of the jet from the wide open gate at maximum discharge.) This chute was 28.45 feet shorter than the preliminary chute and intersected the stilling basin floor 26.55 feet downstream from the gate. The blocks, piers, etc., of the basin floor were moved 28.45 feet nearer the gate. The side walls remained the same as in the preliminary installation which made the intersection of the diverging and the parallel walls occur 16.45 feet downstream from the baffle piers. This installation is shown in Figure 6A.

Flow conditions with this design were unsatisfactory; the jet failed to spread the full width between the diverging walls. A back eddy started in the vicinity of the baffle piers and traveled upstream next to the diverging walls (Figure 6B) causing excessive turbulence in the roller upstream from the crown of the jump.

The divergence of the gate chute was decreased until the chute just contained the spreading jet. These walls were continued until they intersected the parallel basin walls 41.55 feet downstream from the end of the parabolic floor of the chute. Flow in the basin with this design was fair; the roller upstream from the crest of the jump was not as turbulent at high tail water elevations as in the preliminary basin, but fairly large swells traveled through the basin and caused waves which severely eroded the sand-lined canal downstream.

The diverging retaining walls of the chute were replaced with curved walls beginning tangent to parallel lines 5 feet 6-1/2 inches apart at the gate frame and continuing on a radius of 133 feet, intersecting the parallel walls of the basin 40 feet downstream from the gate. The flow followed the curved walls a short distance, but then separated to produce unacceptable back eddies in the areas adjacent to the downstream half of the curved walls.

The parabolic chute floor permitted a decrease in the overall length of the basin and also benefited the action of the jump. However, with the parabolic floor tangent to the downstream invert of the gate frame, the diverging side walls extended a considerable distance downstream from the crest of the jump and had an adverse effect on the flow leaving the basin, as noted above. The jet from the gate apparently would not follow the curved retaining walls.

A series of tests were made in which the downward tilt of the gate was maintained at 15°, and the origin and path of the parabolic floor were changed so that the tangent to the floor at the downstream invert of the gate frame was 15° (tested previously), 12°, 9°, 6°, 3°, and 0°. The profile of each chute floor followed the path of a free jet with an actual velocity of 56 fps at the downstream end of the gate invert (Figure 7B). Figure 7A shows the necessary placement of the diverging training walls to just contain the spreading jet for each of the six floor shapes tested. The chart, Figure 7C, shows the distance from the gate to the downstream end of the parabolic chute, and from the gate to the downstream end of the diverging training walls for floor slopes between 0° and 15° at the gate. These values are for a jet velocity of 56 fps at the gate with a drop of 12.06 feet from the downstream end of the gate invert to the horizontal basin floor, and a basin width of 24 feet at the downstream end of the diverging walls.

The action of the roller upstream from the crest of the jump was similar for each of the tested floor shapes. The swells in the flow downstream from the crest of the jump were quite large when the slope of the chute floor at the gate was 15°, not very pronounced for a 12° slope, and not visible for a 9° slope. From these tests it was determined that the end of the jump should occur in the portion of the basin with parallel walls rather than in the diverging section. Thus, the minimum length of chute was determined to be one in which the baffle piers, and therefore the end of the jump, were near the station of the downstream end of the diverging retaining walls. For this basin with a tail water depth D_2 of 11 feet (estimated minimum), the distance from the chute blocks to the baffle piers should be 8.8 feet.1/ From Figure 7C it was determined that a parabolic chute floor with a slope at the gate frame of 10° would have a diverging wall length about 8-1/2 feet longer than the chute floor length. Consequently, a chute floor following the parabola $X^2 = -188.906\ Y$, and sloping 10° at the downstream end of the gate frame invert, was installed in the model. The downstream end of the chute floor was 33.93 feet from the gate frame, and the downstream end of the diverging walls was 42.50 feet. Nine chute blocks were installed on the downstream end of the parabolic floor, and 6 baffle piers 8.75 feet downstream from the ends of the chute blocks. The dentated sill was placed 42.5 feet downstream from the chute blocks, and the basin floor and retaining walls were terminated at the downstream end of the dentated sill. The general operation of the basin with this design was acceptable; the following refinements were made to obtain optimum flow conditions.

Chute blocks. The axis of the chute blocks in the preceding test was parallel to the basin center line. The crest of the jump was somewhat higher at midstream than near the side walls and the roller upstream from the crest of the jump tended to oscillate from side to side because of this unsteady "crown" of water. When the chute blocks were installed on lines radiating from the projected intersection of the side walls, the flow was more uniform across the basin and the side to side motion of the roller was reduced. It appeared that chute blocks mounted radially in this manner would more nearly follow the lines of flow in the chute and therefore be much less susceptible to cavitation erosion than ones installed parallel to the basin center line. Therefore, the nine chute blocks with the size, shape, and placement shown in Figure 10B are recommended for prototype installation.

Baffle piers. Six baffle piers 2.66 feet high and 2 feet wide with 2-foot spaces between (Figure 10C) were placed from 8 to 15 feet downstream from the chute blocks. For each position of the piers the tail water elevation was varied through the range from the expected maximum to the expected minimum. Each placement was disadvantageous for some tail water elevation; however, a distance of 12.13 feet between chute blocks and baffle piers produced the best operation of the basin for average tail water elevation 2825.5. This placement is the one recommended for prototype construction and is shown in Figure 10A. The jump swept out of the basin at tail water elevation 2821.8.

1/Type III basin, Hydraulic Laboratory Report No. Hyd-399.

Dentated end sill. The preliminary design dentated end sill (Figure 10D) was used without change throughout the model study. With the chute, blocks, and piers installed as recommended above, the flow downstream from the crest of the jump became fairly stable 41 feet from the end of the chute. Therefore the dentated sill was placed near this station 29 feet from the baffle piers (Figure 10A).

The 6:1 sloped concrete apron extension downstream from the dentated sill in the preliminary design was deemed unnecessary since the bottom velocities at the sill were not excessive. This extension was not included in the recommended design stilling basin.

Hooked-type baffle piers. Since the tail water elevation, which could not be precisely determined, might be dangerously near the jump sweep out elevation for the conventional baffle piers, a set of hooked-type baffle piers 2/ was considered as a possible safeguard against jump sweep out. Figure 8C shows the dimensions and location of the piers in the stilling basin. Figure 8A shows the recommended basin but with the hooked-type piers replacing the conventional baffle piers. The flow in the basin was similar to that with the conventional baffle piers, but the tail water elevation at which the jump swept out was 1.5 feet lower. Figure 8B shows the basin operation at the maximum design flow of 1,400 cfs and minimum tail water elevation 2820.3.

These hooked-type baffle piers performed very well for low tail water elevations; however, the designers felt that complicated fabrication and an apparent susceptibility to cavitation erosion precluded their further consideration for the Tiber Dam outlet works.

Pivot valve and chute. The pivot valve operation was satisfactory in the preliminary installation (Figures 3 and 9A) with the maximum design discharge of 115 cfs. The jet from the valve plunged into the stilling pool causing very little splash or spray (Figure 4B). However, changes in the pivot valve chute were made necessary by the requirement that the right retaining wall of the gate chute be continuous past the pivot valve chute exit as determined by the tests of the gate chute.

The pivot valve chute was made horizontal by raising the floor of the chute 4.2 feet at its intersection with the right basin wall. The valve remained as initially installed (Figure 9B). The pivot valve flow with this arrangement was unsatisfactory. The jet struck the horizontal floor of the chute and caused excessive splash and spray where it "skipped" along the surface of the stilling pool toward the downstream end of the left retaining wall (Figure 9C).

2/The hooked-type baffle piers were developed for the Carter Lake outlet works, see Report No. Hyd-394, Figure 19.

From these preliminary tests it was determined that the jet from the pivot valve should be directed downward in such a manner that it would penetrate the stilling pool and not skip along the surface. Tests were made with the pivot valve chute floor removed and with the valve tilted downward 3°, 6°, 9°, 12°, and 15°; the steeper tilt produced the best action of the jet. Various convergences of the pivot valve axis with the gate center line were tested and the appearance of the flow in the basin was best when this convergence was about 6°. Figure 9D shows the pivot valve tilted downward 15° with its axis converging 6° with the basin center line and discharging 115 cfs. This arrangement is included in the recommended design.

Revised Tail Water Elevation

Subsequent to completion of the preceding tests, diversion water at the dam site subsided sufficiently to permit cross sectioning the river outlet channel. The channel shape had changed considerably from the initial cut; a dike sufficiently large to control the flow had been deposited about 250 feet downstream from the gate. A computation based on the survey indicated that for the maximum discharge, 1,400 cfs, the tail water elevation would be 2831.5.

The maximum tail water elevation of 2828.5 was limited by the turbulent water in the roller upstream from the crest of the jump surging against the gate frame and drowning the flow at the gate. The new requirement that the basin should operate satisfactorily for a tail water elevation of 2831.5 could be met if the gate and basin were raised about 3 feet.

Recommended Design Stilling Basin

Slide gate. Construction work on the river outlets at the project was continuing concurrently with the model study and the contract for fabrication of the 72-inch-diameter to 60-inch-square transition (Figure 3) had already been awarded. This transition was placed in line with the 72-inch conduit, followed by a 30-foot radius, 15° bend, 5 foot square in cross section to which the high pressure slide gate was attached. This installation retained the 15° slope of the gate but raised it 2.93 feet.

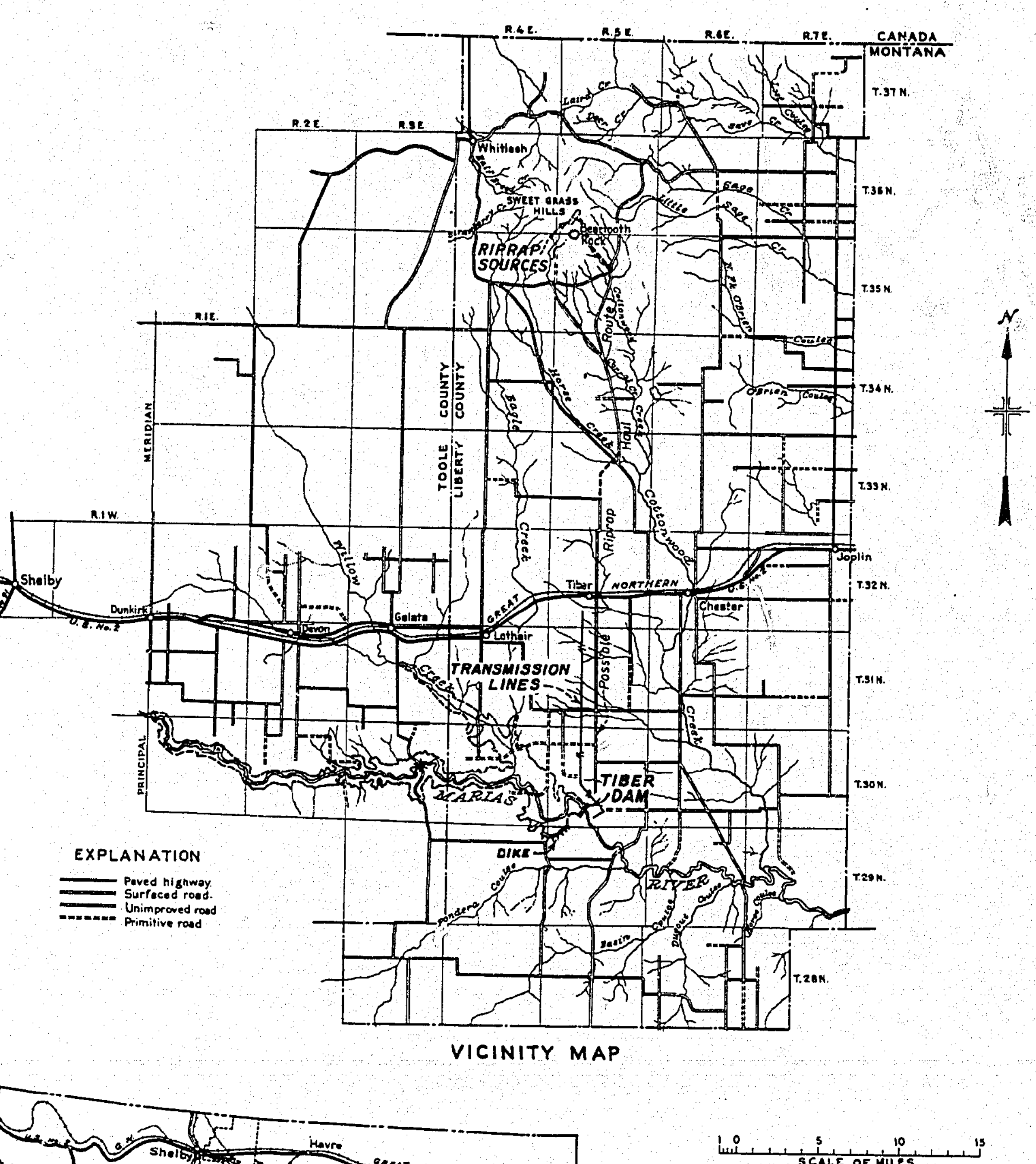
Basin floor. Since the probability of very low tail water no longer existed, the floor of the stilling basin was raised from elevation 2811.0 to 2814.0, about the same amount that the gate was raised, in order to realize a saving in excavation costs. The change in the chute, resulting from raising the basin floor, was not significant.

The pivot valve was placed 7.25 feet to the right of the gate center line at elevation 2832.2 and Station 39+54.71. It was tilted downward 15° and directed inward to converge 6° with the center line of the basin.

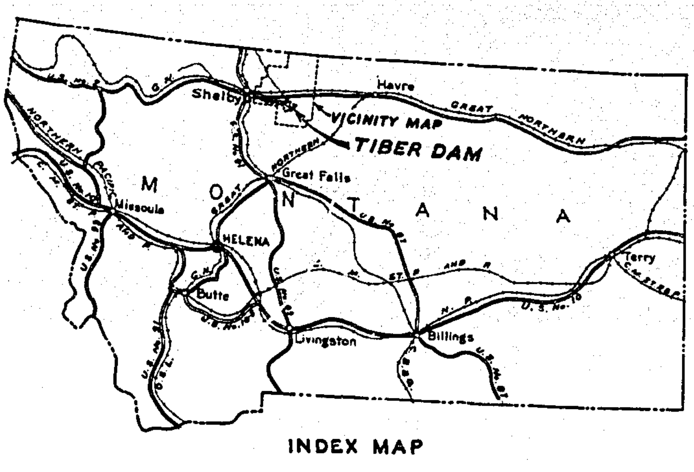
Operation. Flow conditions were satisfactory for all discharges up to and including 1,400 cfs. With the slide gate fully opened and discharging 1,400 cfs the flow conditions in the basin were acceptable for tail water elevations between 2825.6, just above jump sweep out (Figure 12A,) and 2831.5 where the roller upstream from the crest of the jump backed up against the gate frame (Figure 13A). The pivot valve flow was acceptable for any tail water elevation.

Scour. With the basin terminated at the downstream edge of the dentated sill, the canal downstream was shaped in wet sand to form a trapezoidal channel with side slopes 2-1/2:1 and a bottom width of 30 feet at elevation 2819.0 (Figure 11B). The model was operated for 10 hours (prototype time) at the maximum design discharge of 1,400 cfs and minimum tail water elevation 2825.6, and again for 10 hours at maximum tail water 2831.5. In each case the scour was quite deep at the toe of the basin and tended to undercut the floor. The basin floor and side walls were extended 5 feet downstream from the end sill and the scour tests repeated. The flow and scour pattern for minimum tail water is shown in Figures 12A and 12B, and for maximum tail water in Figures 13A and 13B. Since the depth of scour at the toe of the basin was decreased appreciably by the 5-foot extension downstream from the end sill, this extension is recommended for the prototype.

The recommended river outlet works stilling basin (Figures 10A and 11A) will operate satisfactorily throughout the foreseeable range of discharges and tail water elevations at Tiber Dam. The overall length of the basin is 86.00 feet--46 feet shorter than the basin of the preliminary design.



VICINITY MAP



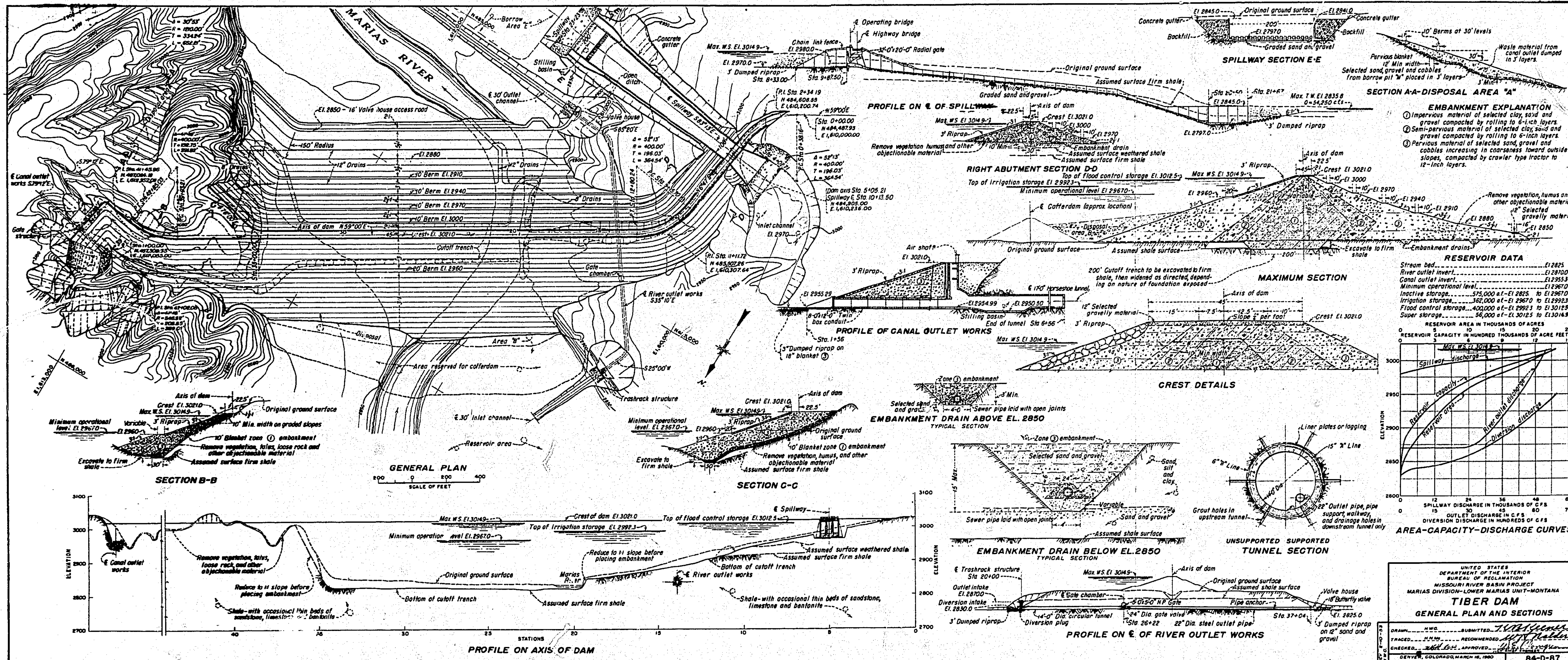
INDEX MAP

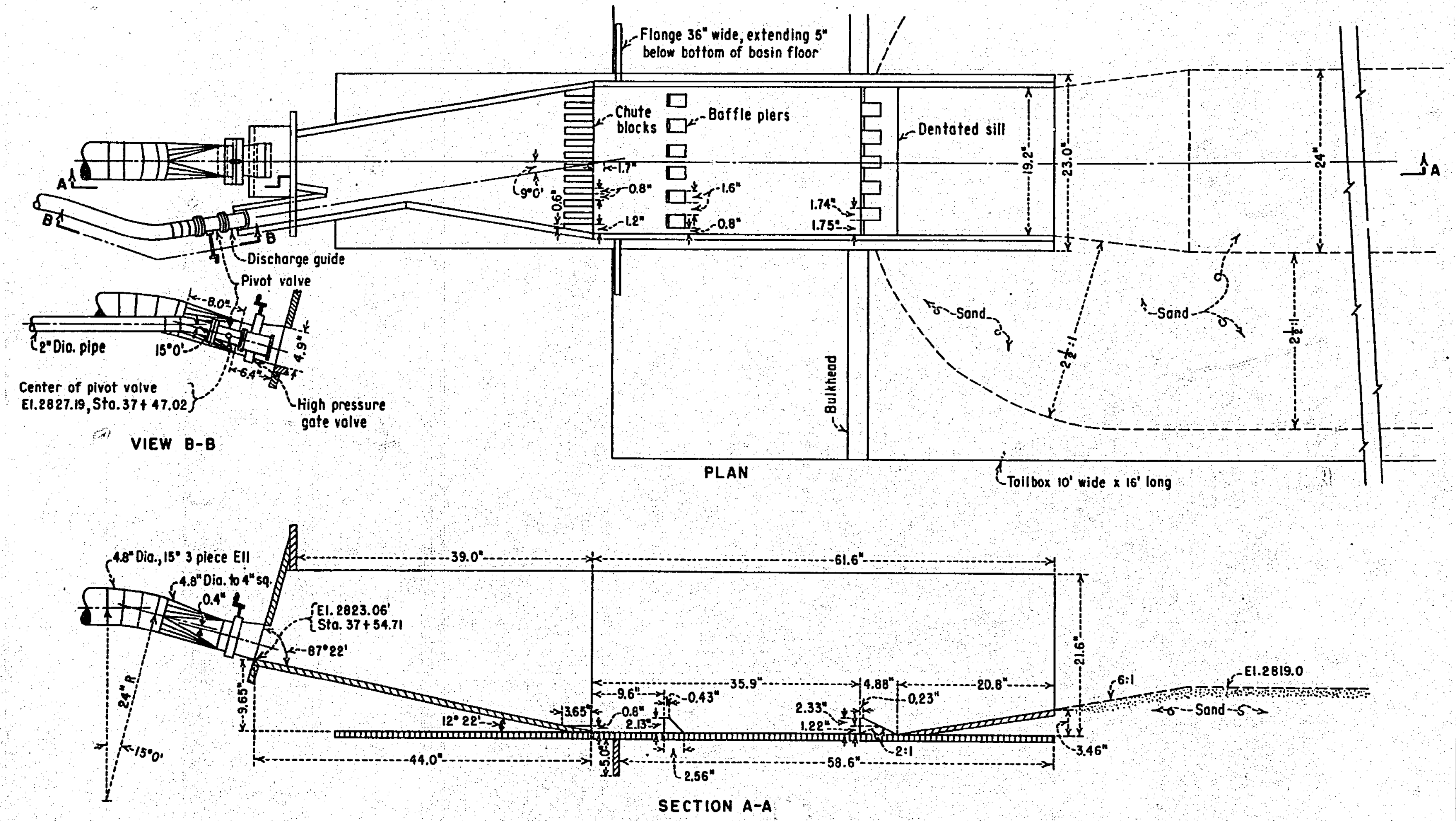
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MISSOURI RIVER BASIN PROJECT
LOWER MARIAS UNIT-MONTANA

TIBER DAM
LOCATION MAP

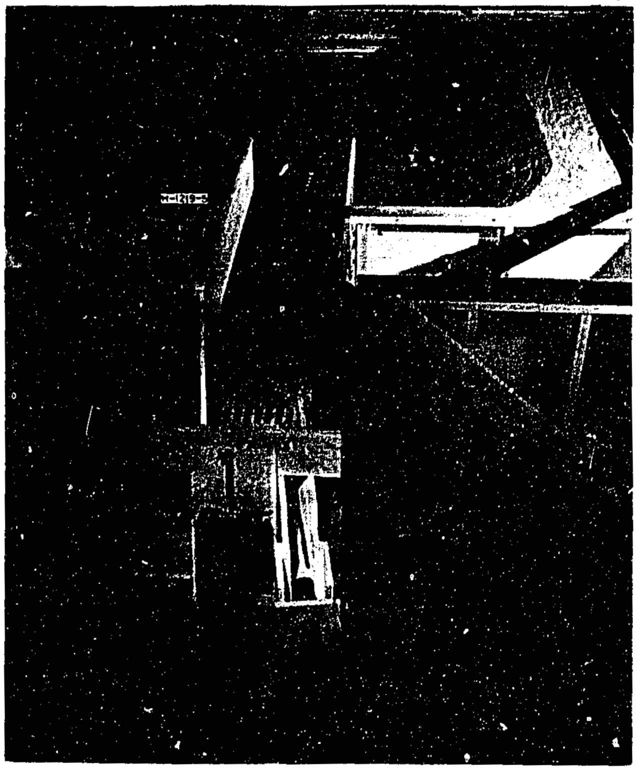
DRAWN: R.C.R. SUBMITTED: *[signature]*
TRACED: M.C.F. RECOMMENDED: *W. T. Nalder*
CHECKED: *[initials]* APPROVED: *W. E. R...*
ACTING CHIEF ENGINEER
DENVER, COLORADO, MARCH 16, 1950 | 84-D-74

FIGURE 2
REPORT HYD. 402

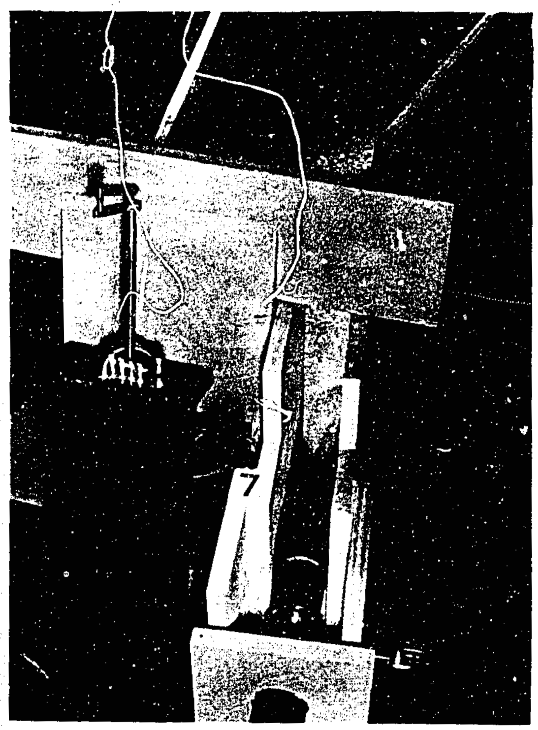




TIBER DAM RIVER OUTLET WORKS
PRELIMINARY MODEL INSTALLATION
MODEL SCALE 1:15

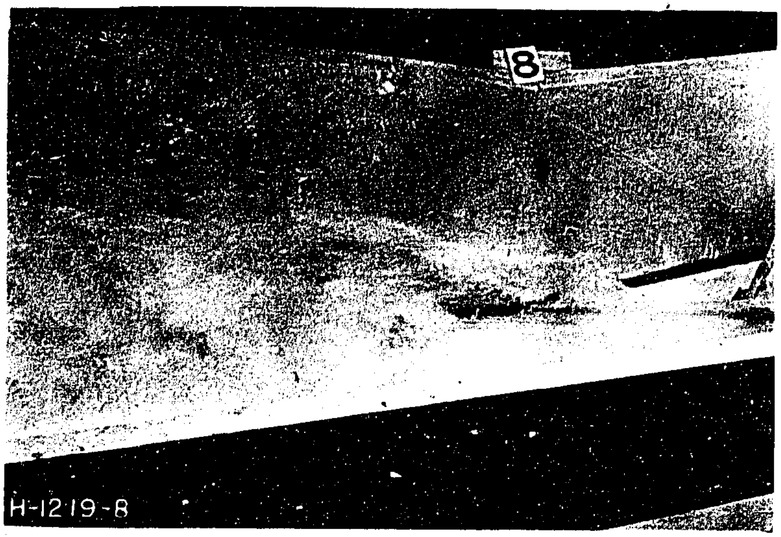


A. Preliminary installation.

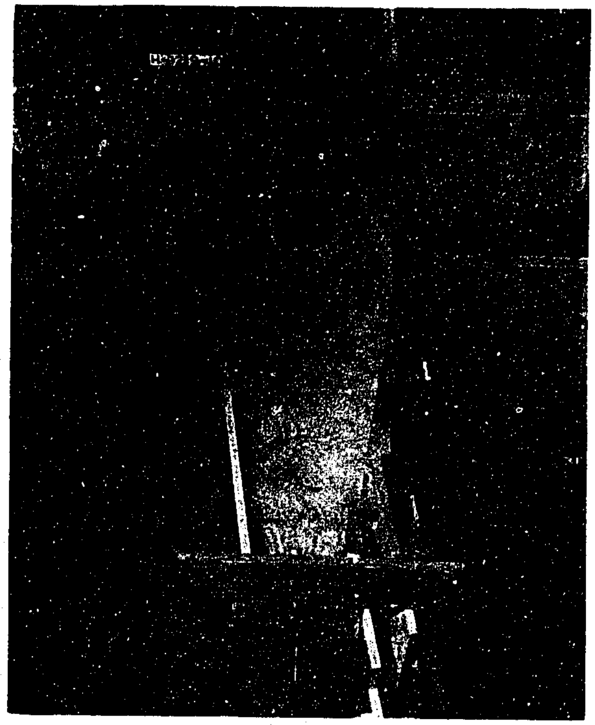


B. Pivot valve discharging 115 cfs.

MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Preliminary Stilling Basin Design
Model Scale 1:15

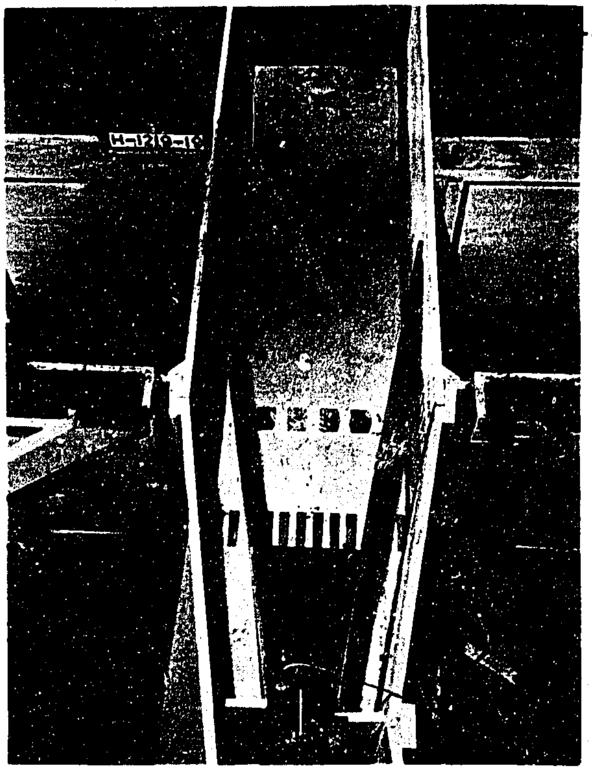


A. Preliminary design--gate fully opened, Q = 1,400 cfs, T. W. elev = 2823.0. Note fin caused by pivot valve chute.

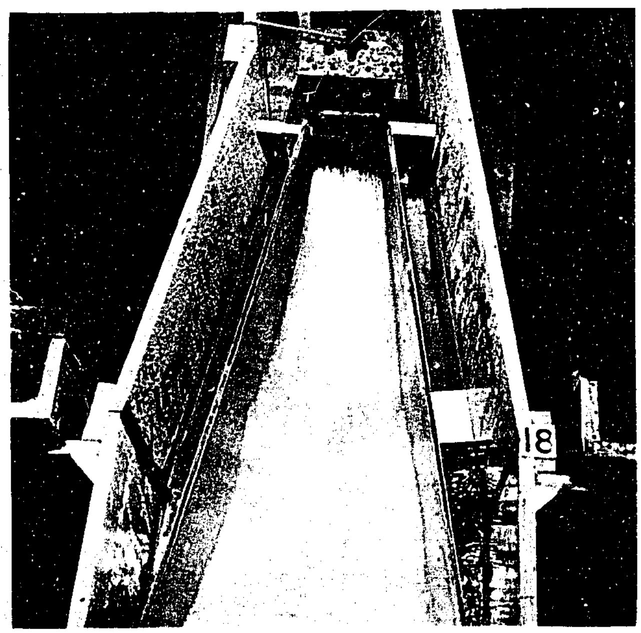


B. Right retaining wall continued through pivot valve chute. Gate fully opened, Q = 1,400 cfs, T. W. elev = 2823.0.

MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Flow disturbance in the stilling basin at the downstream end of the valve chute
Model Scale 1:15

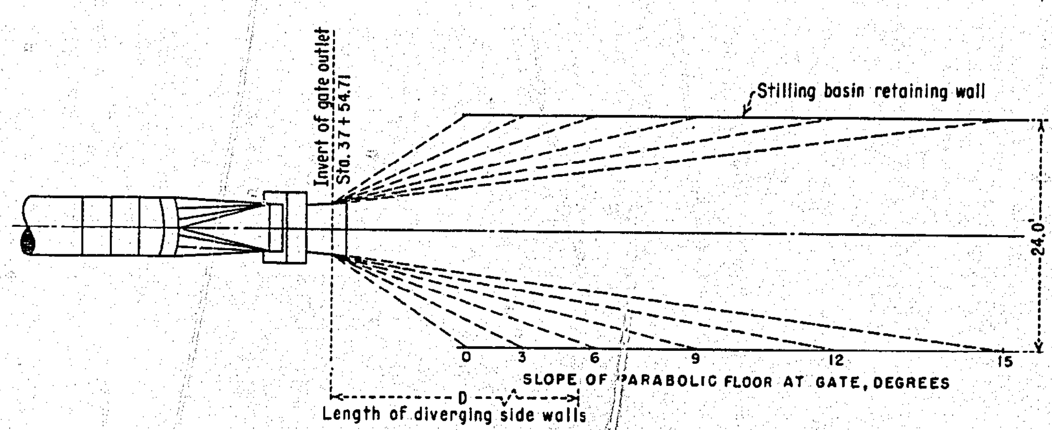


A. View showing 4 baffle piers and 6 chute blocks.



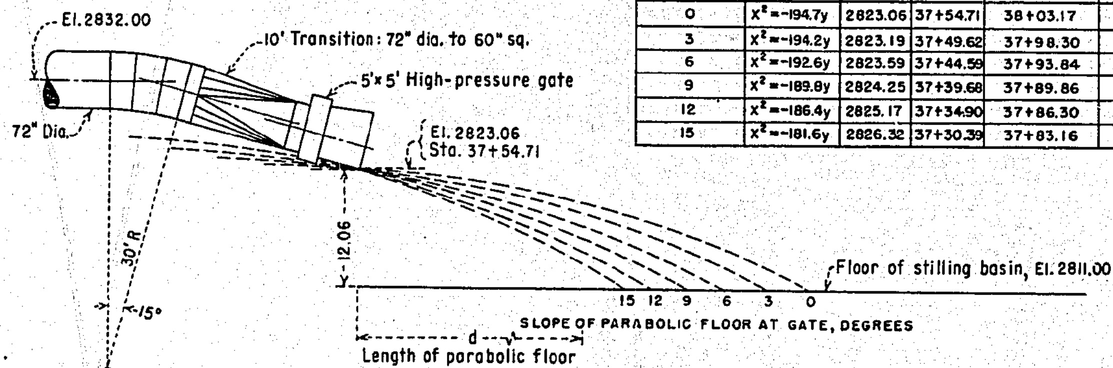
B. Gate fully opened. Q = 1,400 cfs. Note improper spreading of the jet.

MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Stilling basin shortened 25 feet, parabolic chute floor tangent to the gate invert
Model Scale 1:15

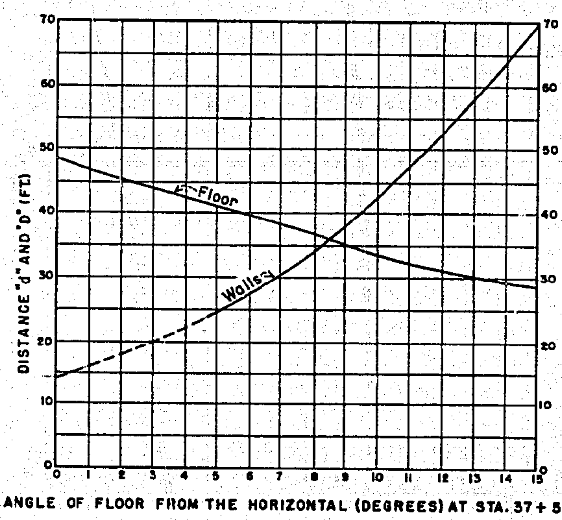


A-PLAN

SLOPE OF PARABOLIC FLOOR AT GATE FRAME DEGREES	PARABOLA	ORIGIN OF PARABOLA		JUNCTION OF PARABOLA AND BASIN FLOOR	DOWNSTREAM END OF DIVERGING SIDE WALLS
		ELEV.	STA.	STATION	STATION
0	$x^2=-194.7y$	2823.06	37+54.71	38+03.17	37+68.71
3	$x^2=-194.2y$	2823.19	37+49.62	37+98.30	37+74.71
6	$x^2=-192.6y$	2823.59	37+44.59	37+93.84	37+82.11
9	$x^2=-189.8y$	2824.25	37+39.68	37+89.86	37+92.56
12	$x^2=-186.4y$	2825.17	37+34.90	37+86.30	38+07.04
15	$x^2=-181.6y$	2826.32	37+30.39	37+83.16	38+24.71



B-ELEVATION

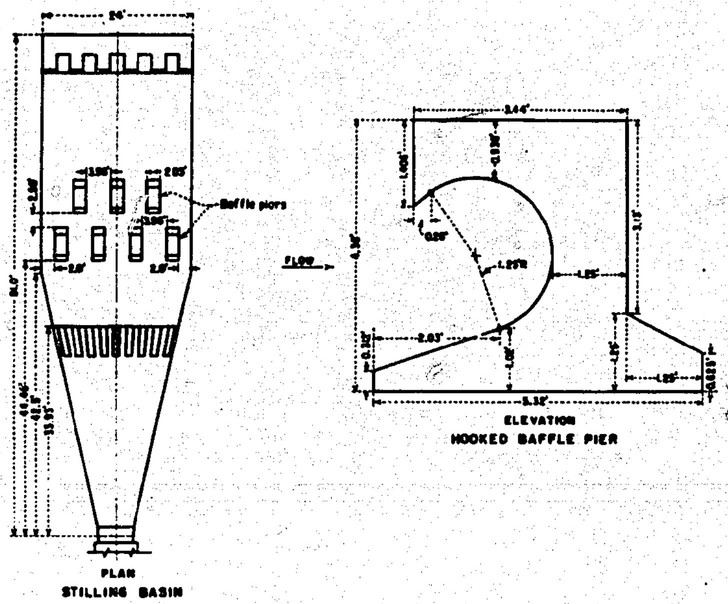


C—CHART SHOWING OVERALL LENGTH OF FLOOR AND WALLS

TIBER DAM RIVER OUTLET WORKS
STILLING BASIN WALL AND CHUTE LOCATION TESTS
MODEL SCALE 1:15

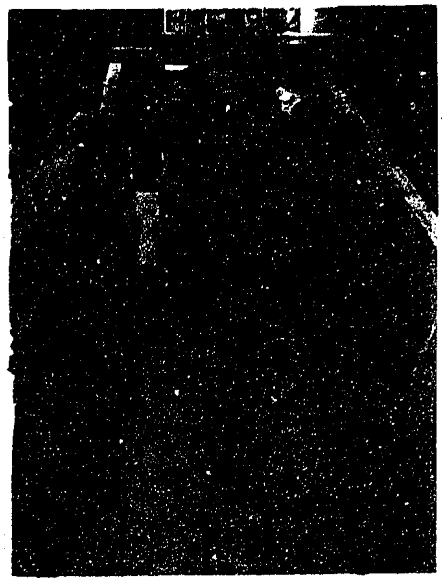
A. Pier installation.

B. Q = 1,400 cfs, T. W. elev = 2820.3.

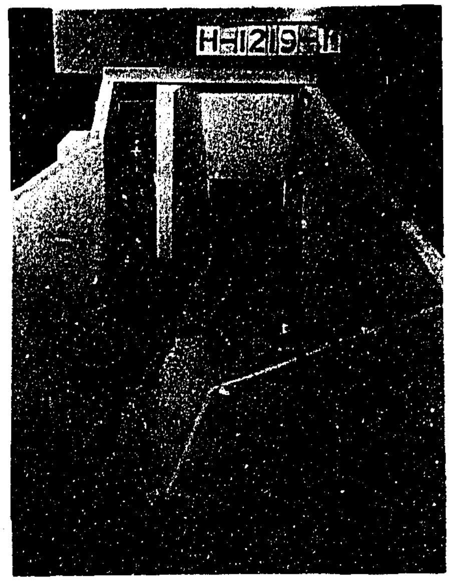


C. Hooked-type baffle pier details and installation dimensions.

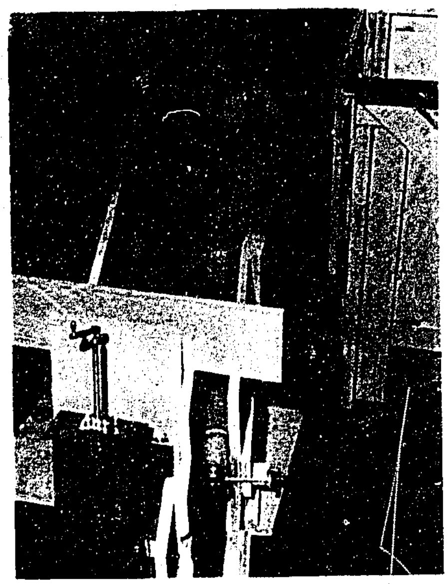
MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Stilling basin with hooked-type baffle piers
Model Scale 1:15



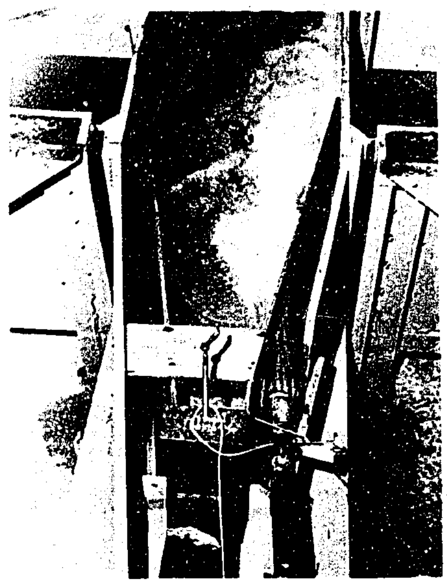
A. Preliminary installation, pivot valve tilted downward 15^{o} and converging 9^{o} with the gate center line.



B. Pivot valve same as in A. Pivot valve chute floor raised 4.2 feet at basin wall and continued horizontal back to the valve.

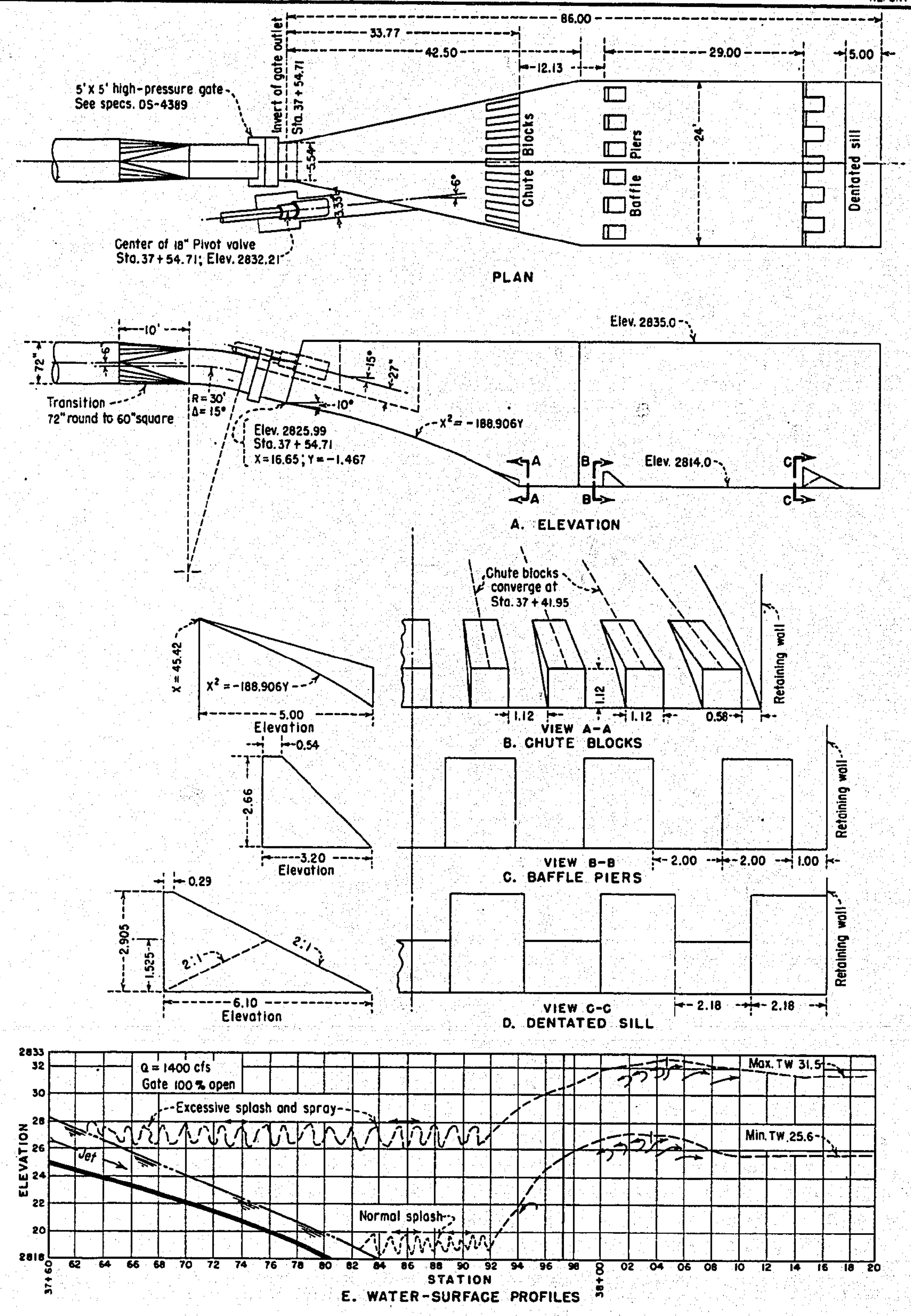


C. Installation same as in B. Pivot valve discharge 115 cfs, T. W. elev = 2823.0.

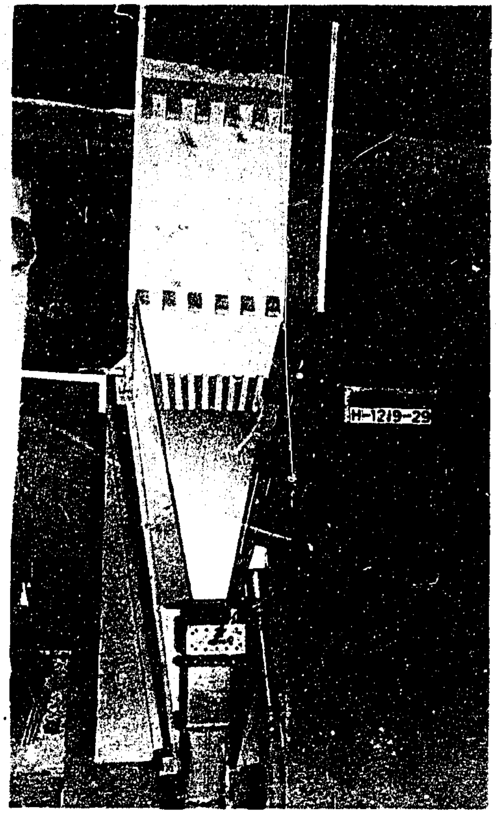


D. Valve tilted downward 15^{o} converging 6^{o} with the gate center line, and placed 6 feet above the gate invert. Pivot valve discharge 115 cfs, T. W. elev = 2821.0

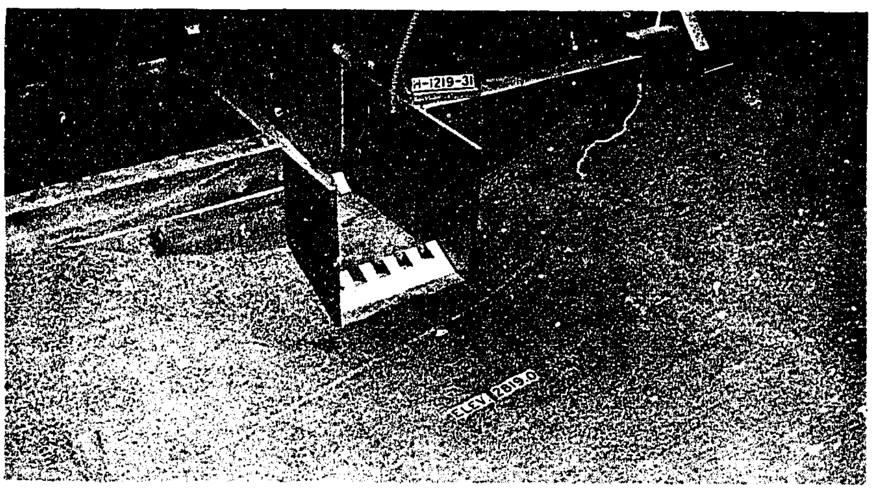
MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Conditions in Stilling Basin, Pivot valve operating
Model Scale 1:15



TIBER DAM RIVER OUTLET WORKS
RECOMMENDED STILLING BASIN DESIGN AND WATER SURFACE PROFILES
MODEL SCALE 1:15

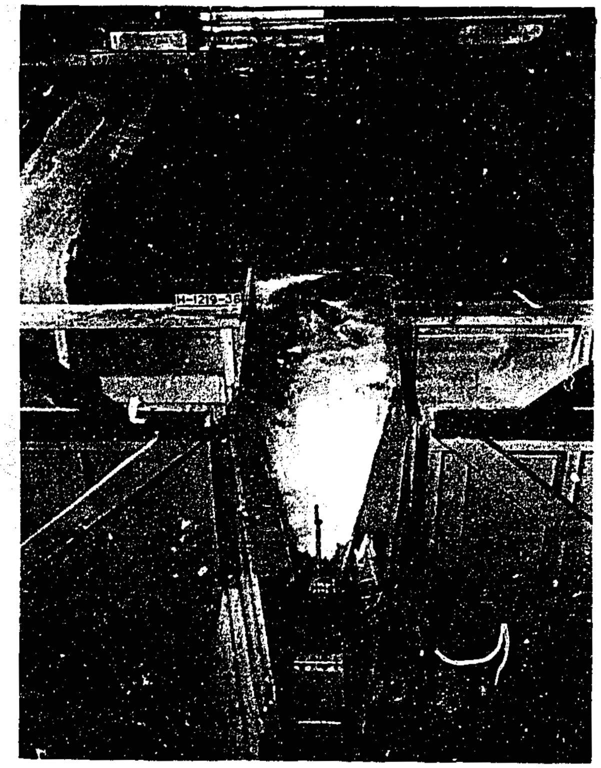


A. Control structure and
stilling basin.



B. Downstream channel before scour tests.

MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Recommended Stilling Basin Design
Model Scale 1:15

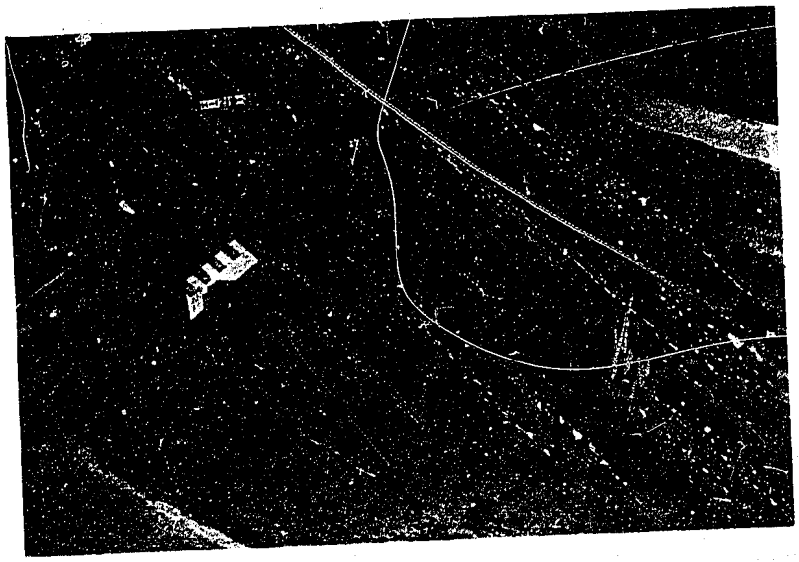


A. Gate fully opened, Q = 1,400 cfs, minimum T. W. elev = 2825.6.

B. Scour after 2-1/2 hours of flow shown in A above.

MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Recommended Stilling Basin Design
Scour tests, minimum tail water
Model Scale 1:15

A. Gate fully opened, Q = 1,400 cfs, maximum T. W. elev = 2831.5.



MISSOURI RIVER BASIN PROJECT--MONTANA
Tiber Dam--River Outlet Works
Recommended Stilling Basin Design
Scour tests, maximum tail water
Model Scale 1:15